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HARD COSMIC RAY SHOWERS *

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Plate III.

In the year 1931 Heidecke observed an increase of number of coincidence of cosmic rays when he put Pb sheets between the counters which were not placed in the same vertical line. He explained these results to be due to scattering of the primary cosmic rays.

Later on Rossi took up this experiment and showed that new secondary cosmic rays in the form of showers are produced by the inter-action of matter with primary cosmic rays. He found also that the maximum number of secondary cosmic rays are produced by 1·56 cm. thickness of Pb and then a gradual absorption follows up to about 10 cm. thickness. The existence of these secondary particles was beautifully shown by Blackett and others in the Wilson chamber photographs. Anderson by the analysis of these shower photographs discovered the positron—a positively charged particle of electronic mass.

Ackemann, Hummel and others observed that by increasing the thickness of Pb, again secondary particles are produced which reaches its maximum at about 17 cm. thickness of Pb. Drigo found that these secondary particles are entirely absorbed by 1 cm. thickness of Pb—a result which seems at first quite surprising. The shower producing rays having range of 17 cm. thickness of Pb produces secondary rays which have only 1 cm. range.

The showers of first kind are groups of positive and negative electrons which approximately proceed from the same point and cover a tolerably large range of angles, on the average 20° about the axis. Their penetrating power is rather low, about 2 cm. of Pb absorbing the shower particles nearly completely. What I intend to report today concerns the showers of second kind which differ from the usual showers not only in the above-mentioned characteristics, but also in the way in which they originate.

You see here (fig. 1) an experimental arrangement, which does not appear to be very different from those which Rossi and many others after him have utilized for the investigation of shower: four Geiger tubes are in coincidence arrangement, the two upper ones being connected in parallel, above that is the shower producing layer in variable thickness; betwen the upper and

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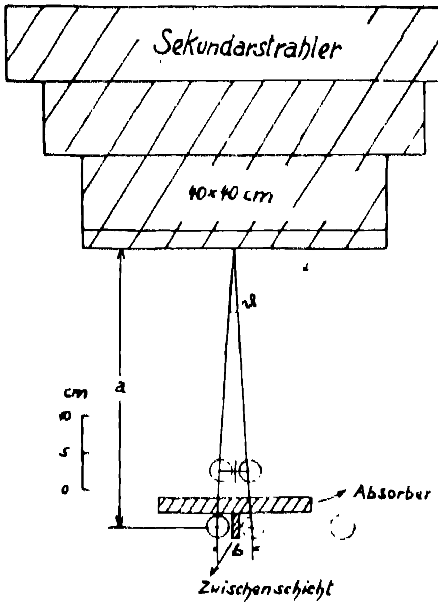


FIGURE 1.

lower pairs of counters an absorber of different thickness may be inserted. By altering the thickness of the shower-producing layer, one can obtain the Rossi-curves. This has a very pronounced maximum at 1·7 cms. of lead. By altering the thickness of the absorber, one obtains the absorption curve of the particles. All the curves which have been obtained so far, show that the usual sort of shower particles are absorbed, for the most part, by

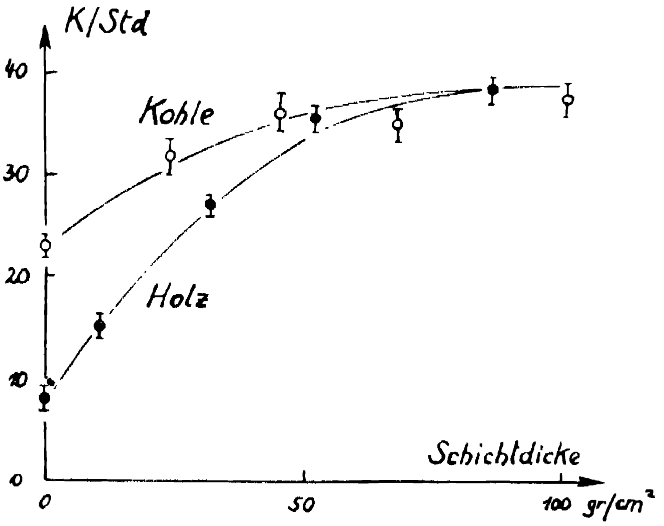


FIGURE 2

2 cms. of lead. Accidentally, with our arrangement, we made a different observation: when we inserted 2 cms. of lead between the counters, we obtained still more than half of the coincidences, which occurred without the absorber. This signifies that a secondary corpuscular radiation comes from the matter above the counters, which is essentially more penetrating than the known shower particles. We also took their Rossi-curve, by altering the thickness of the shower-producing layer.

You see, that up to a thickness of about two hundred grams per cm^2 the curve rises, whereas for lead, for a thickness exceeding 18 gm/cm^2 the curve goes down. This also means that the saturation thickness of our secondary particles is greater than that of the useful showers. What could be the cause of it? Our arrangement differs from t e usual in two points: firstly, the shower-producing substance consisted of light atoms (carbon, wood); secondly, the angular distance of the counters, as seen from the layer, was particularly small, therefore coincidences could only be produced by two particles, which subtend only a small angle at each other. It was to be tested, as to which of these two points was essential. We tested first the second point, the dependence of the penetrating power of the secondary particles on the angle of divergence. For this purpose, either the counters had to be brought into greater or smaller distance from each other in horizontal direction, or the whole counter arrangement had to be brought into greater or smaller distance from the shower-producing layer.

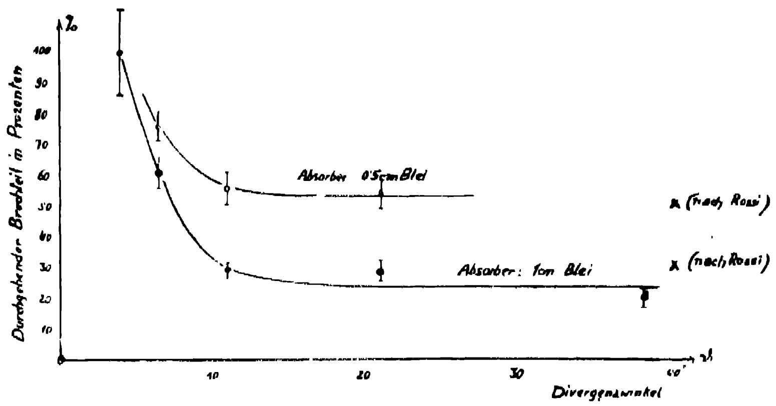


FIGURE 3.

In the next diagram (fig. 3) the abscissa are the angles of divergence, the ordinates are the frequencies of coincidences, relative to the frequency without the absorber. The two curves hold for an absorber, of 0·5 and 1 cm. of lead each. You see, the answer to our question is clear. At large angles you find the well-known penetrating power of the usual shower particles: 1 cm. of lead absorbes more than half. On the other hand, at small angles the particles are much more penetrating, and at 4° one cm. of lead absorbs only a small part of the shower particles. We conclude there from, that the hard showers occur only at angles smaller than 10°.

You may ask why these showers have never been observed before? It is very remarkable, but it appears that up to this time no one has made observation at so small angles. At the same time, a phenomenon is already known from which it can be inferred that possibly it is connected with our hard showers, that is, the so-called second maximum of the Rossi-curve. If the Rossi-curve be continued till to much larger thickness of the shower-producing layer, then it again begins to rise, and it attains a second maximum at about 17 cms. of lead. This large saturation thickness signifies again a hard secondary radiation. It is true, the existence of this second maximum has been called into question by certain authors. But in every case it could be supposed that here we have also a reaction of the hard showers. This question could be very simply tested: one has to measure the Rossi-curves for different angles of divergence. The result of such measurements is shown in the next figure (fig. 4).

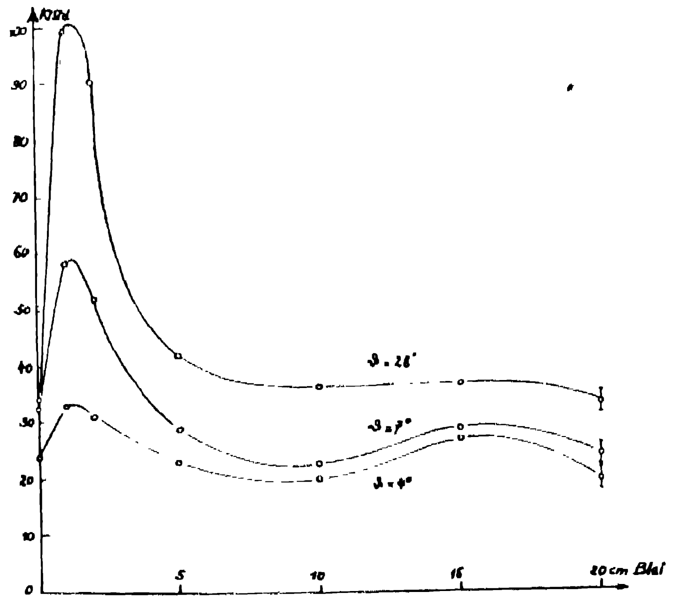


FIGURE 4.

I believe that here the result is also very clear. At an angle of divergence amounting to 28°, the second maximum can scarcely be recognised; at 7°, the second maximum appears quite distinctly, and at 4°, it is almost as high as the first maximum. Now we have seen that in fact the hard showers occur only at angles smaller than 10°, therefore no doubt can remain that the second maximum

Fig. 6 (a)

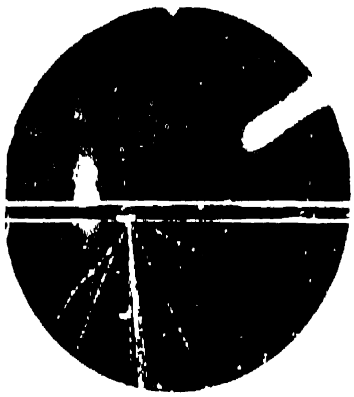


Fig. 6 (b)

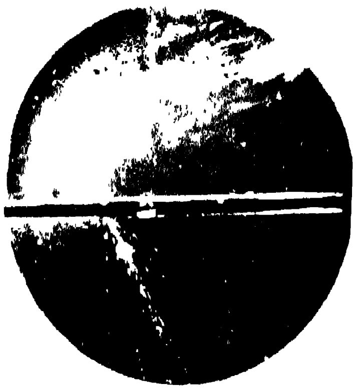
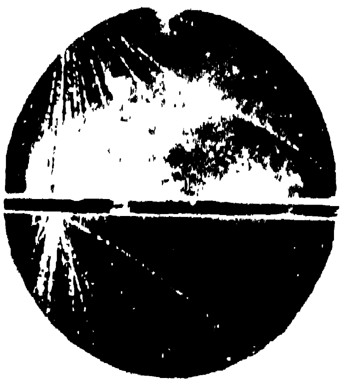


Fig. 6 (c)



Cosmic ray showers.

is produced by the same hard showers as we have observed. At the same time, it becomes clear why the observations made so far were so contradictory. It has not been grasped that the angle is of such importance.

Actually, this question is somewhat more complicated, as I intend to say in brief. We have seen that at angles greater than 10°, the second maximum is very insignificant, but it still exists, the intensity has not diminished to zero. A further difficulty appeared, as we measured more accurately the absorption curves of the shower particles under different conditions. If we observe in the second maximum, and the angle of divergence is large, we get no hard showers, but the usual soft showers At first, it seems unintelligible that a secondary radiation reaches its saturation in as much as 17 cms. of lead, while it is almost completely absorbed in 2 cms. of lead. I shall now show how these two observations can be reconciled. The particles which are observed in this case are of tertiary origin.

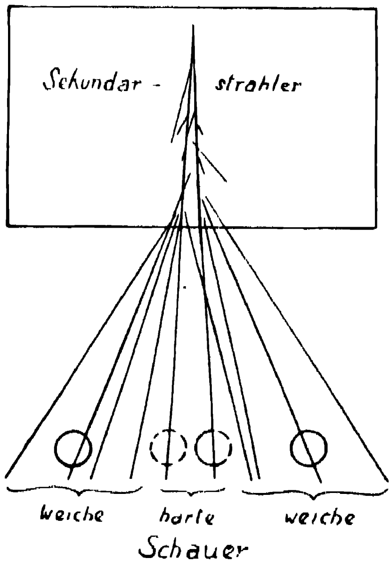


FIGURE 5.

The hard showers themselves are able to produce soft showers, and this process comes forth already in the shower-producing layer itself. These tertiary showers have apparently all the characteristics of the usual soft showers, in particular, they have large angles of divergence. Therefore at large angles, the hard showers cannot directly produce coincidences, but can do so by the circuitous way of the tertiary soft showers

It is now very interesting that all these deductions find a strong support in some Wilson photographs, which Auger and Ehrenfest have published, after we have made our first communication about the hard showers. In the next figure (plate III) you see a shower of small angular divergence. We are now convinced that this is the new kind of shower. This shower is surrounded by a usual shower of large divergence. According to our conceptions, the soft shower is produced by the hard one, in the interior of the layer.

Another photograph (fig. 6 c) obtained by Auger and Ehrenfest shows a compound shower coming from above, the hard shower releases out of a layer of lead a tertiary shower; that is exactly the process which we have assumed.

Now I wish to make a few short remarks about the generation of the hard showers. The question arises, how does the intensity of the hard showers depend on the nature of the shower-producing substance.

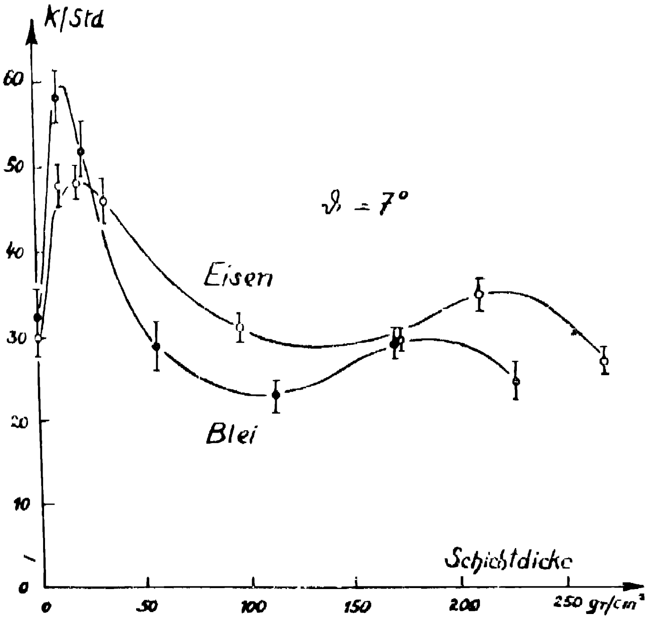


FIGURE 7.

In the next diagram (fig. 7) you see the Rossi-curves for lead and iron, taken under identical conditions. The first maximum is clearly lower for iron than for lead. This is not new, but has been verified by different observers. It has been established that for a small thickness, the intensity is approximately proportional to Z^2 per atom. This result obviously holds for the soft showers which produce the first maximum. But the matter is quite otherwise for the second maximum which is produced by the hard showers. Here the intensity is at least as great for iron as for lead, the intensity therefore appears to be approximately proportional to Z per atom. This may be an important criterion for distinguishing between the two kinds of showers.

Finally, we may ask about the primary radiation which produces the hard showers.

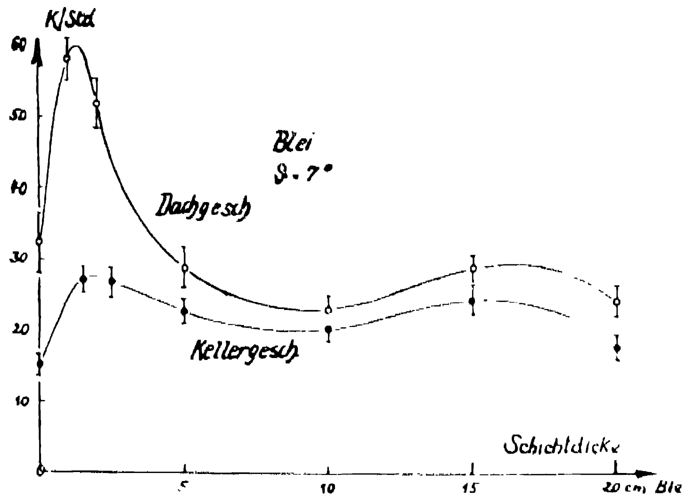


FIG. 8.

In the next diagram (fig. 8) you see the Rossi-curve for lead, obtained under the same conditions, but firstly under the roof of the Institute, then under the basement. The intervening ceilings had about 270 gm/cm^2, they worked as filter for the shower-producing primary radiation. You see that by filtering the primary radiation, the first maximum is strongly reduced ; the second maximum, on the other hand, shows little difference. This shows that the soft showers are produced by the so-called soft component of the primary radiation, as has been known for a long time ; the hard showers on the other hand are produced by the hard component of the primary rays. This is again an important criterion for distinguishing between the two kinds of showers.

Here I must not forget to mention that some time ago Rossi has already made similar experiments : they were not so complete, that any definite conclusions could be drawn from them, but Rossi had already suspected that the shower phenomena are of a complex nature

I am afraid that I have busied myself too long with description of the experiments, carried out in the main part by K. Schmeiser. But to my great sorrow, I can give no theory of these phenomena. Perhaps, in this case, the new particles assumed by Anderson, and Street and Johnson play a part

In final, I may say, that after all what we know of the shower phenomena, we must distinguish between at least three kinds of showers : firstly, the soft showers, which, according to Bhabha and Heitler, arise through the mutual conversion of electrons into photons and *vice-versa* ; secondly, the hard shower, about the nature of which we know very little, and thirdly, the Heisenberg showers or, explosion showers, which can be conceived as arising out of evaporating nuclei, and which appear to be realised in the stars obtained on photographic plates exposed to cosmic rays, as was demonstrated to you by Prof. Taylor, and which have also been observed by Blau and Wambacher in Vienna.